

# Reinhold Environmental Ltd.



## 2009 APC Round Table & Expo Presentation

*July 12-14, 2009, in The Woodlands, TX*

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# Coal, Biomass, Co-firing, Alternative Fuels: Which Way to Go?



*For Energy and  
Environmental  
Solutions*

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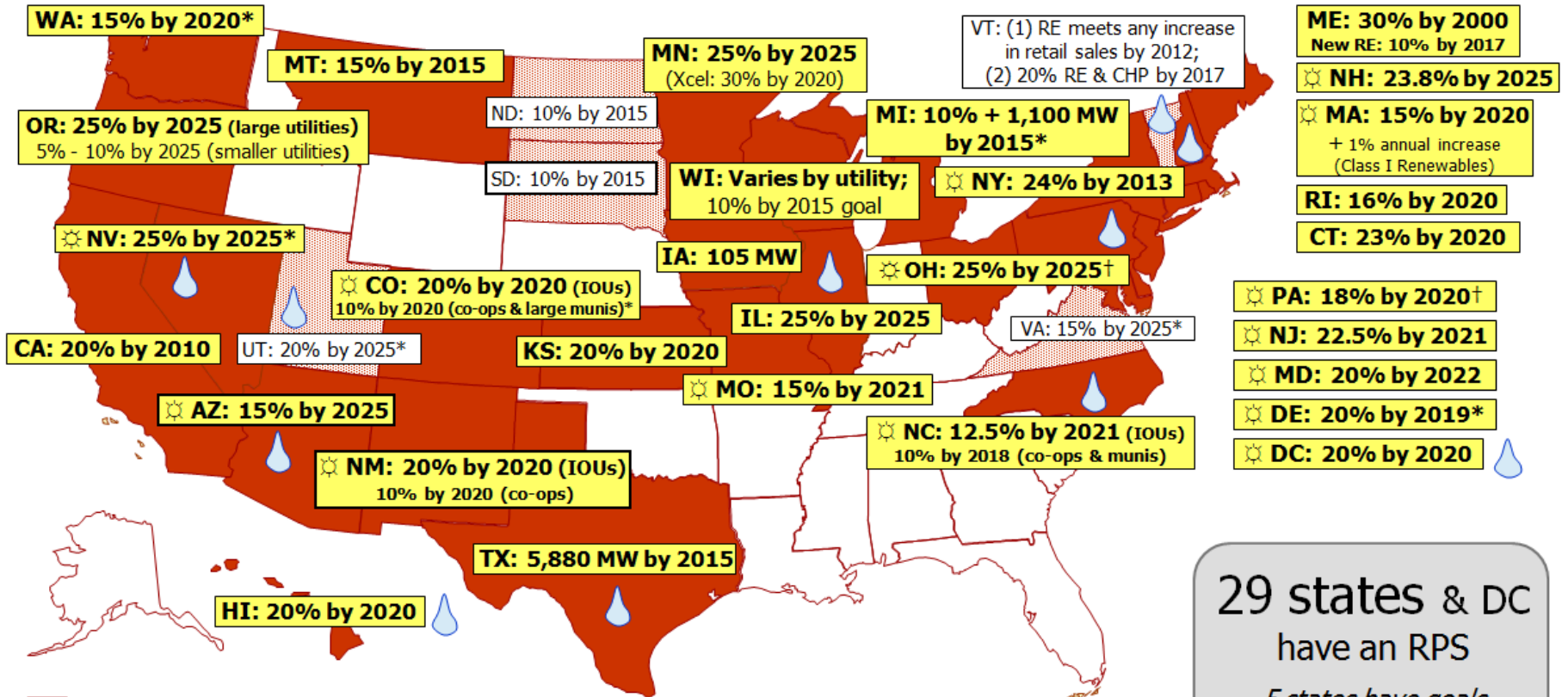
<http://www.reaction-eng.com>

**Air Pollution Control Roundtable**

*The Woodlands, TX • July 12-13, 2009*

# State Renewable Portfolio Standards

[www.dsireusa.org](http://www.dsireusa.org) / July 2009

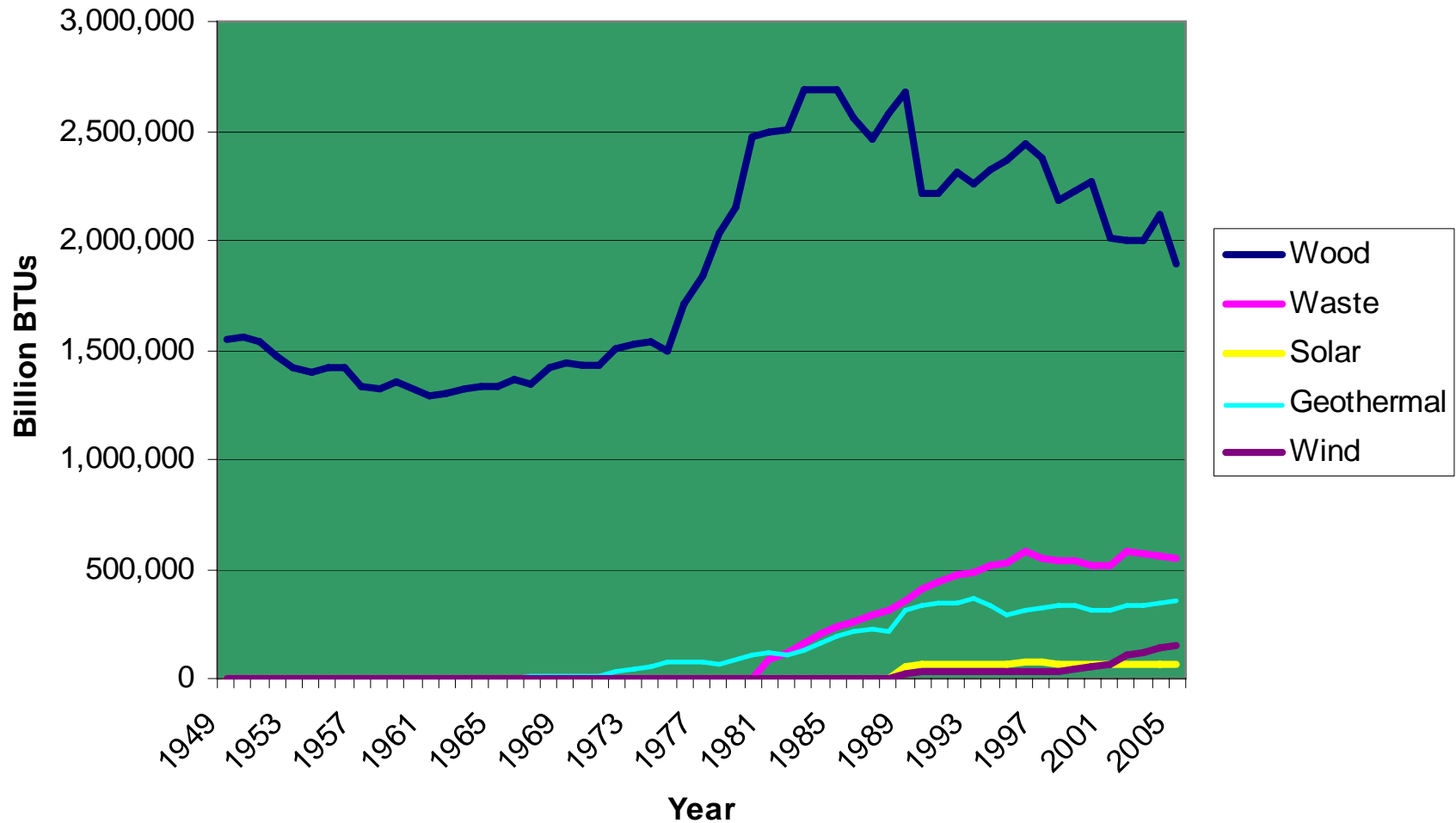


**29 states & DC**  
have an RPS  
*5 states have goals*

- State renewable portfolio standard
- State renewable portfolio goal
- Solar water heating eligible

- ☀ Minimum solar or customer-sited requirement
- ✱ Extra credit for solar or customer-sited renewables
- † Includes separate tier of non-renewable alternative resources

# Renewable Energy Picture



# Biomass Power

➔ Single largest source of non-hydro renewable power

**Table 5. U.S. Electric Net Summer Capacity, 1999-2003**  
(Megawatts)

Source	1999	2000	2001	2002	<sup>E</sup> 2003
<b>Total</b>	<b>785,927</b>	<b>811,719</b>	<b>848,254</b>	<b>905,307</b>	<b>953,206</b>
<b>Renewable Total</b>	<b>95,335</b>	<b>94,931</b>	<b>95,664</b>	<b>96,109</b>	<b>96,669</b>
Biomass	10,454	10,016	9,709	9,689	9,799
Wood/Wood Waste	6,795	6,147	5,882	5,844	5,916
MSW/Landfill Gas	3,214	3,381	3,292	3,330	3,367
Other Biomass <sup>A</sup>	446	488	535	515	516
Geothermal	2,846	2,793	2,216	2,252	2,252
Conventional Hydroelectric	79,393	79,359	79,484	79,354	79,366
Solar	389	386	392	397	397
Wind	2,252	2,377	3,864	4,417	4,854
<b>Nonrenewable Total</b>	<b>690,592</b>	<b>716,788</b>	<b>752,590</b>	<b>809,193</b>	<b>856,537</b>

- ➔ 9,733 megawatts (MW) in 2002
  - ◆ 5,886 MW of forest product and agricultural residues
  - ◆ 3,308 MW of generating capacity from MSW
  - ◆ 539 MW of other capacity such as landfill gas

➔ Classes:

- ◆ Direct-fired
- ◆ Co-fired
  - » Co-mingled
  - » Separate injection

# Biomass Firing

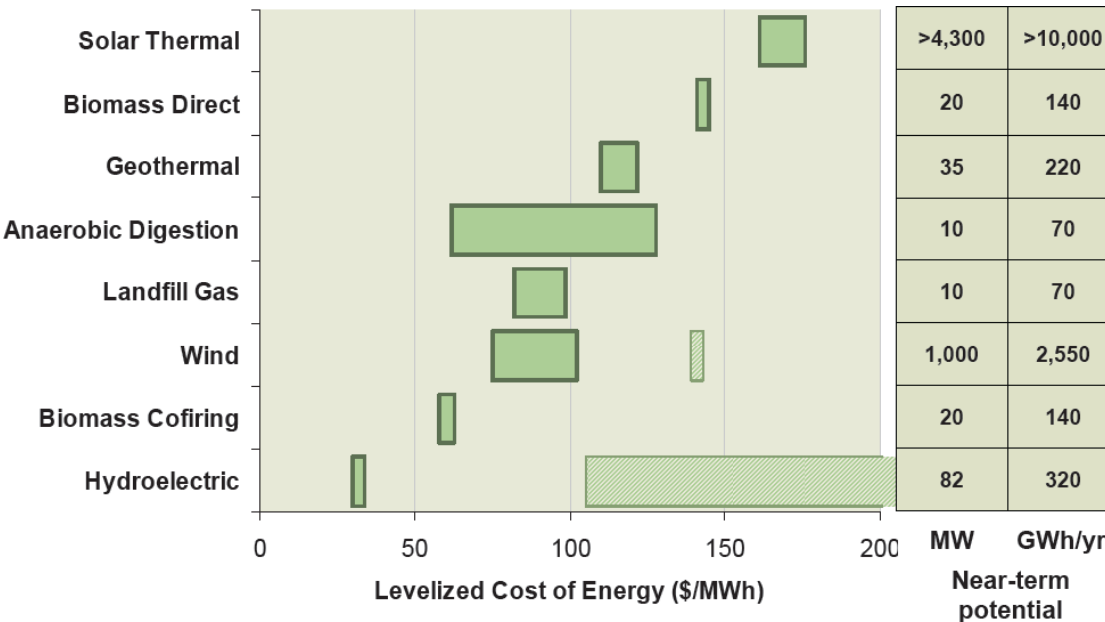
## → Direct-firing

- ◆ Number of small grate-fired units, common in pulp & paper industry
- ◆ Schiller – 50MW Fluidized Bed – wood

## → Co-firing

- ◆ Bailey – 475 MWe cyclone – wood
- ◆ Willow Island – 188 MWe cyclone – wood
- ◆ Seward/Albright – 150 MWe T-fired – wood
- ◆ Gadsden – 70 MWe T-fired – switchgrass
- ◆ Ottumwa – 725 MWe T-fired – switchgrass
- ◆ Dunkirk – 100 MWe T-fired – wood (poplar)
- ◆ Gadsden – 70 MWe T-fired – wood
- ◆ Mitchell – 150 MWe T-fired – switchgrass
- ◆ Polk – 250 MWe IGCC - wood
- ◆ Greenidge – 110 MWe T-fired – wood

Black & Veatch, EUEC 2008.



# Success Story: AES Greenidge - Biomass Processing



Biomass Processing Building



Wood Delivery



Yard Bin



Collision Mill Size Reduction

# AES Greenidge Station

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- Began co-firing work in 1996 as a member of the Salix Consortium.
- Greenidge Station was one of the first cofiring demonstrations in the United States participating in the Biomass Power for Rural Development Program.
- Unit 4 continues cofiring activities at Greenidge.
- Greenidge continues to lead renewable energy efforts partnering with NYSERDA, USDOE, USDA, and USDOJ.

# Issues to Consider

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→ Fuel collection, handling, storage and preparation

→ Performance

- ◆ Heat transfer/balance
- ◆ Combustion stability
- ◆ Slagging/fouling

→ Emissions

- ◆ Carbon Dioxide
- ◆ Sulfur Oxides
- ◆ Mercury
- ◆ Fine Particles
- ◆ Nitrogen Oxides

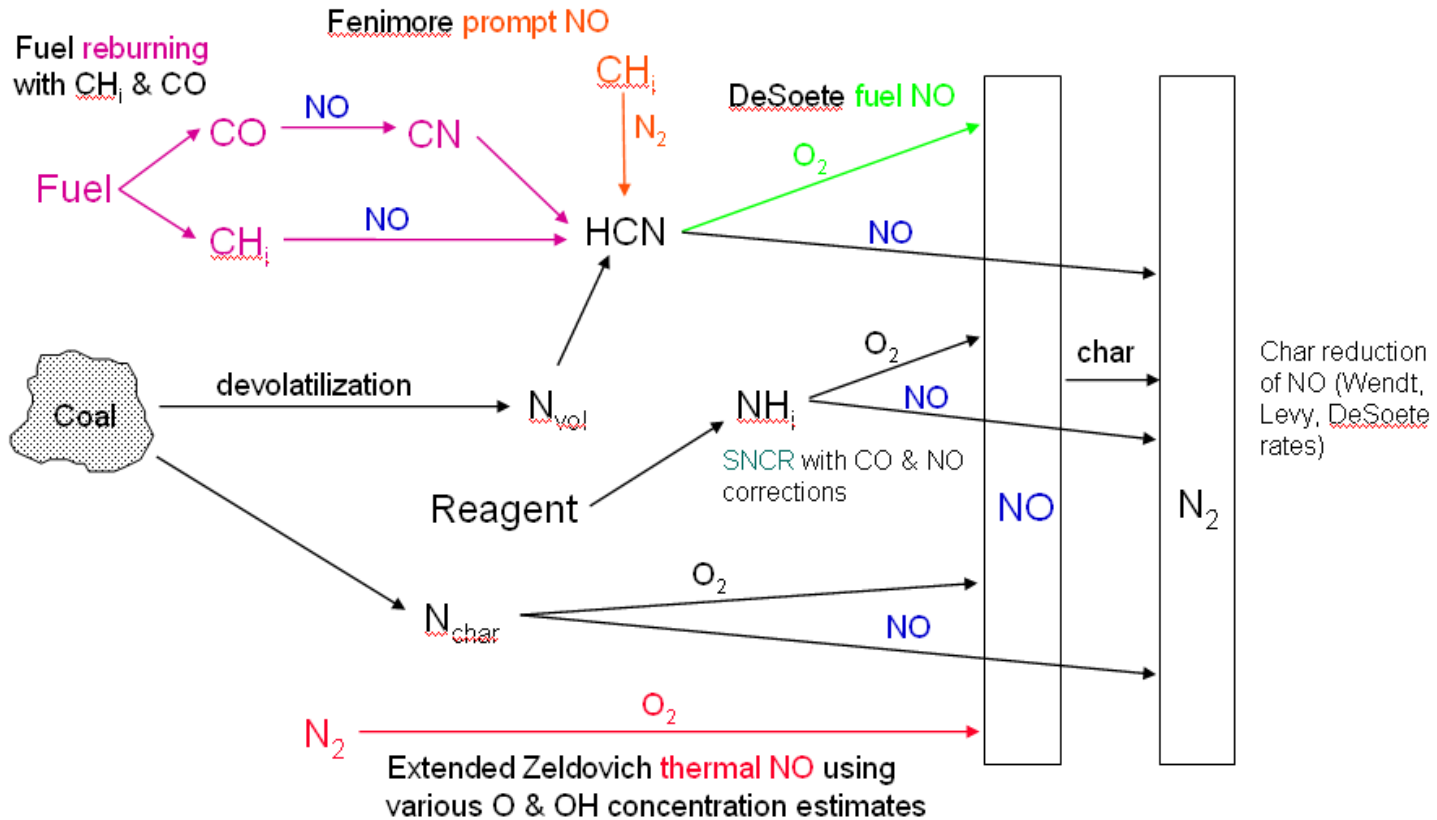


→ Other

- ◆ Catalyst impacts
- ◆ Flyash properties
- ◆ Corrosion
- ◆ Economics
- ◆ Policy

# NOx Fundamentals

- ➔ Fuel NOx
- ➔ Thermal NOx
- ➔ Prompt NOx

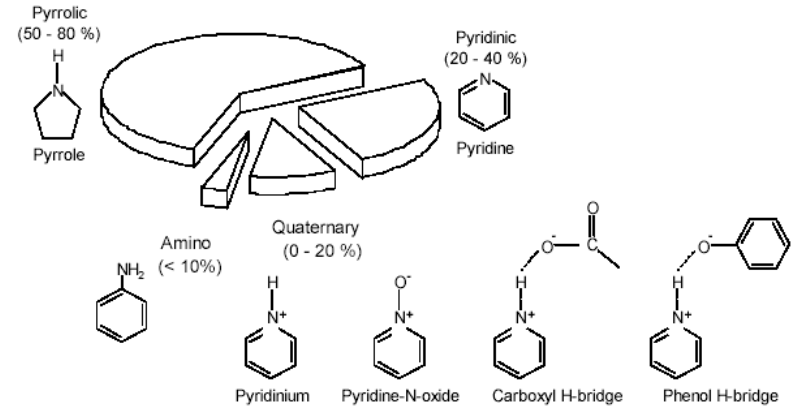


Char reduction of NO (Wendt, Levy, DeSoete rates)

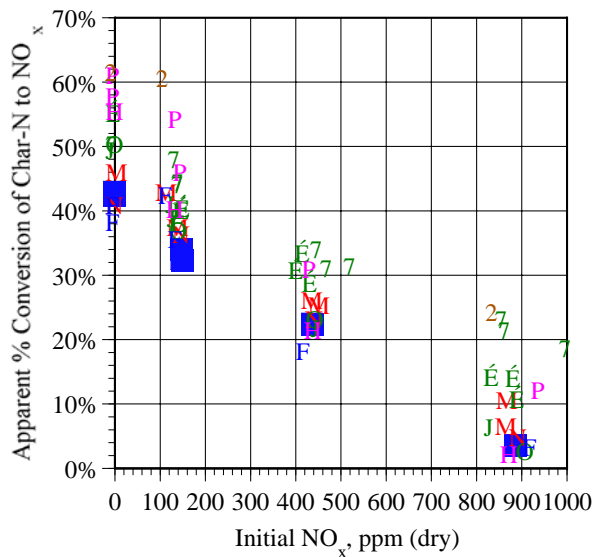
# Fuel NOx

## ➔ Fuel NOx from pyrolysis products

- ◆ Fuel nitrogen content
- ◆ Pyrolysis yield (coal rank)
- ◆ Preferential nitrogen release



Molina, PhD Thesis (2002)



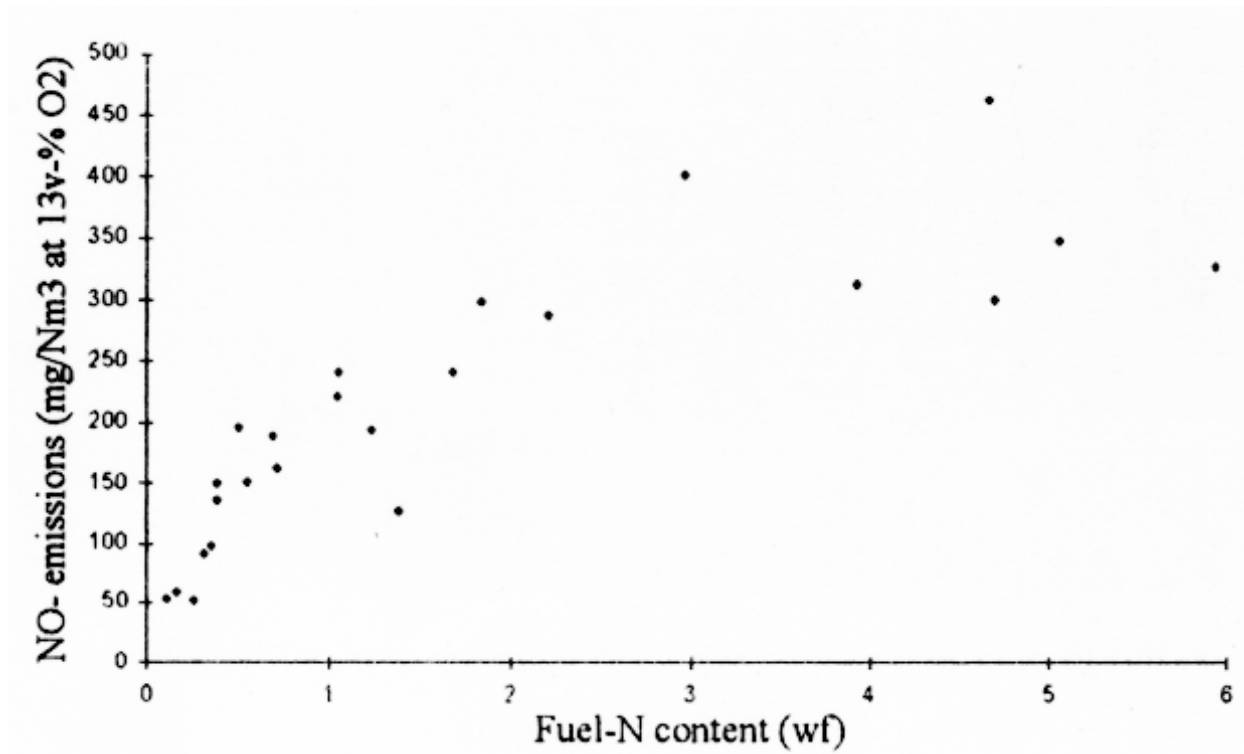
■	Pitt (25,26,29 sept)-1.0 wt%N
N	Pitt (19,24 oct)-1.06 wt%N
M	Pitt (27,28,29 sept)-1.14 wt%N
J	Ill (14,19,20,21 sept)-1.13 wt%N
O	Ill (16 oct)-1.13 wt%N
É	Ill (22 sept)-1.28 wt%N
7	Ill (18 sept)-1.61 wt%N
F	Utah (13 sept)-1.14 wt%N
H	K.R. (26 oct)-0.46 wt%N
P	K.R. (31 oct,1 nov)-0.51 wt%N
2	Black Thunder-0.48 wt%N

## ➔ Fuel NOx from char oxidation

- ◆ Char yield
- ◆ NOx in gas-phase

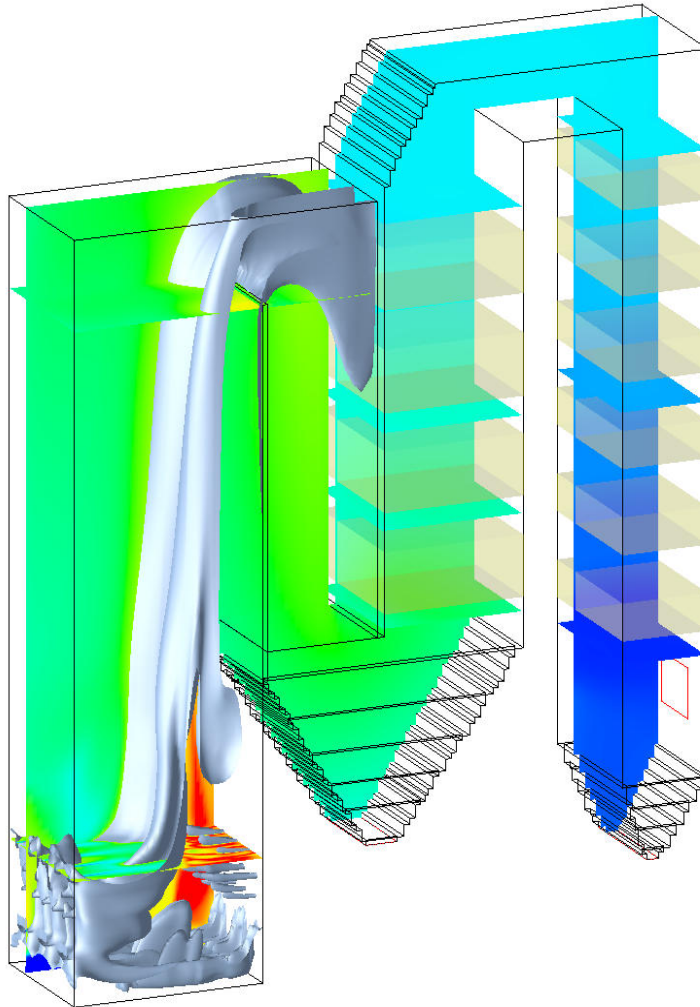
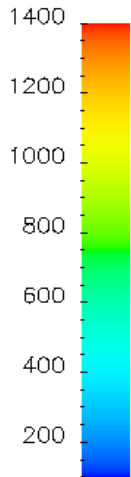
# NO<sub>x</sub> Emissions: Grate-fired Boilers

Reisinger et al. (1996)



# Increasing Regulation of Industrial Boilers

Temperature [°C]



Secondary  
Air Level

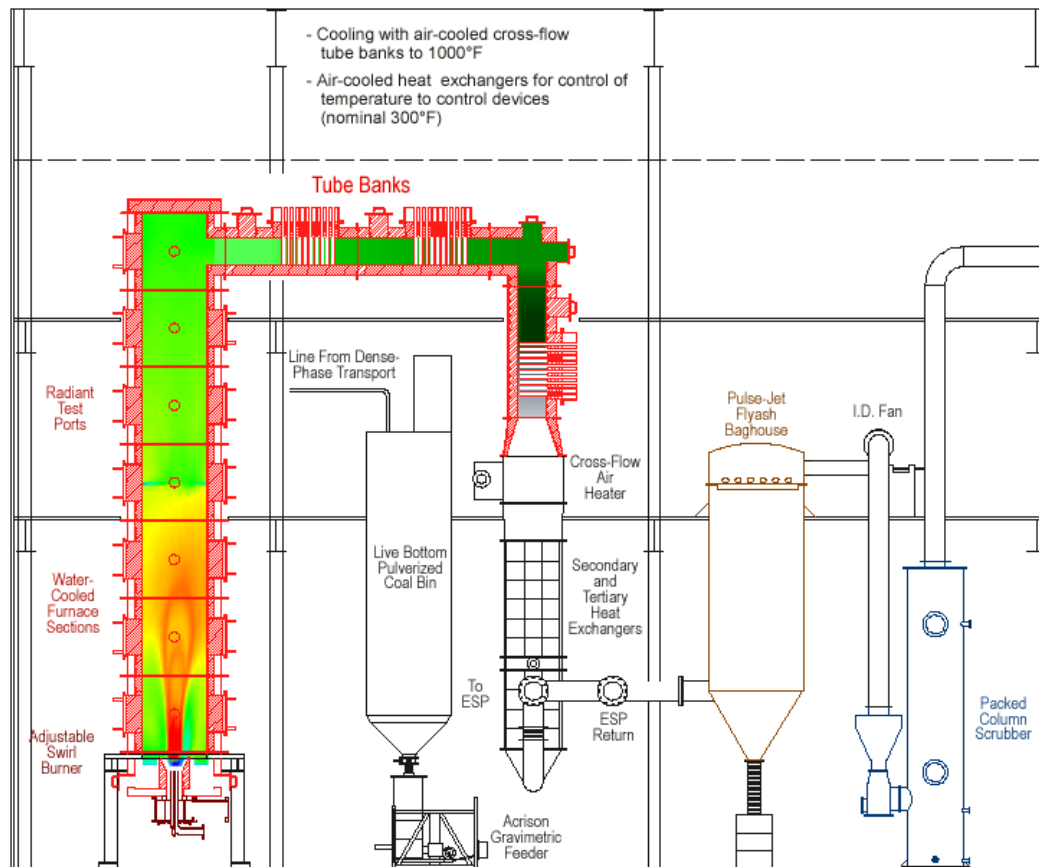
2 sec @ >850 °C  
under oxidizing  
conditions

NO<sub>x</sub> emissions:

Fuel N of 0.03% – 138  
mg NO<sub>x</sub>/Nm<sup>3</sup>, dry

Fuel N of 1.0% – 845  
mg NO<sub>x</sub>/Nm<sup>3</sup>, dry

# Biomass Injection Strategies



→ Southern Research Institute facility designed to reproduce pc boiler conditions

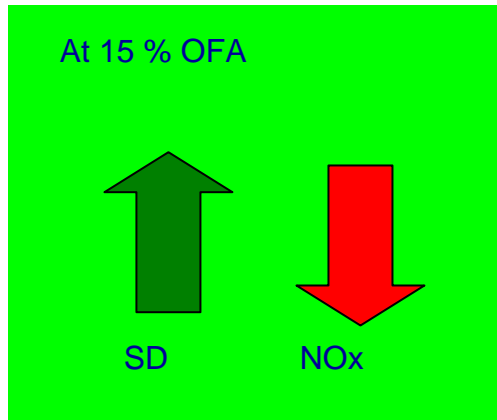
→ Injection Strategies

- ◆ Co-milled
- ◆ Separate center injection

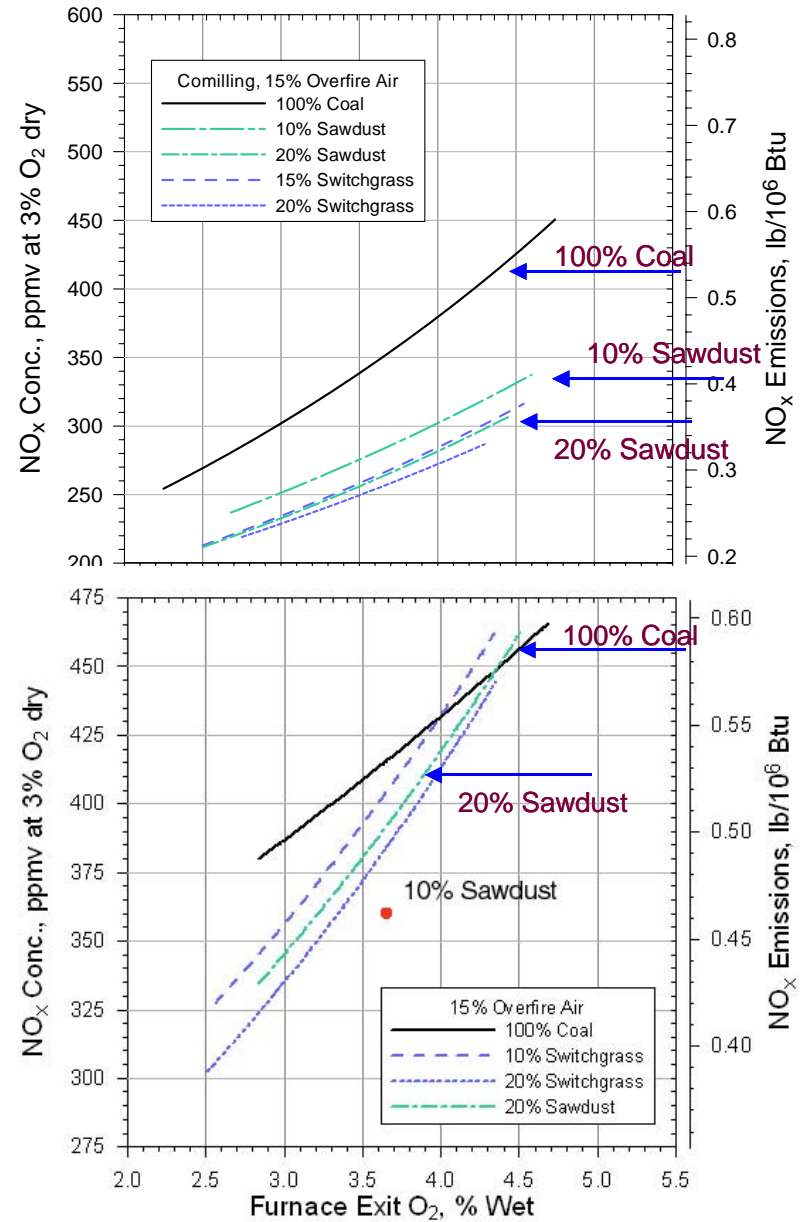
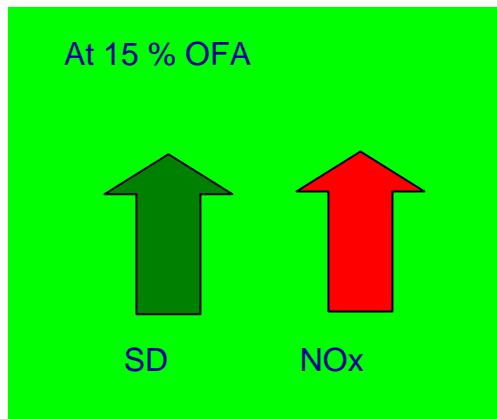
→ Detailed CFD modeling with biomass-specific submodels

# NO<sub>x</sub> Measurements during Testing

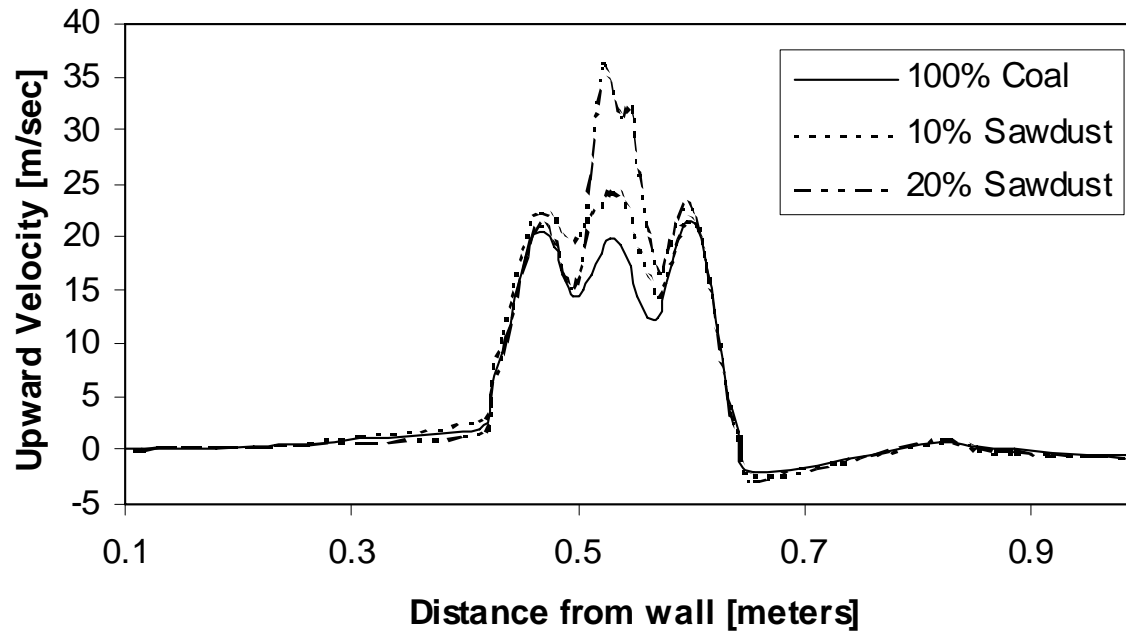
Co-milled



Center Injection

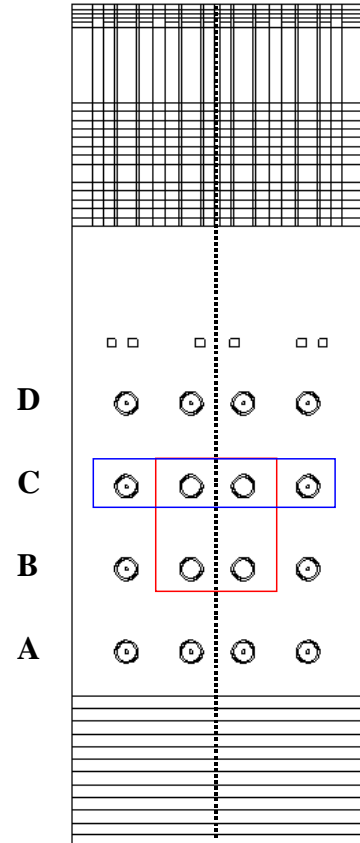


# Near Burner Velocity Profile



# Full-scale Application

- ➔ 150 MW front wall-fired boiler
- ➔ 16 Low NO<sub>x</sub> burners in 4 elevations and OFA
- ➔ Co-firing scenarios
  - ◆ 7% Green Wood Chips based on total heat input.
  - ◆ Separate center injection
    - » Multifuel burners in "C" row.
    - » Multifuel burners at center 2 locations in B, and C rows
- ➔ Determine operational impacts
  - ◆ NO<sub>x</sub> Reduction
  - ◆ carbon-in-flyash
  - ◆ CO



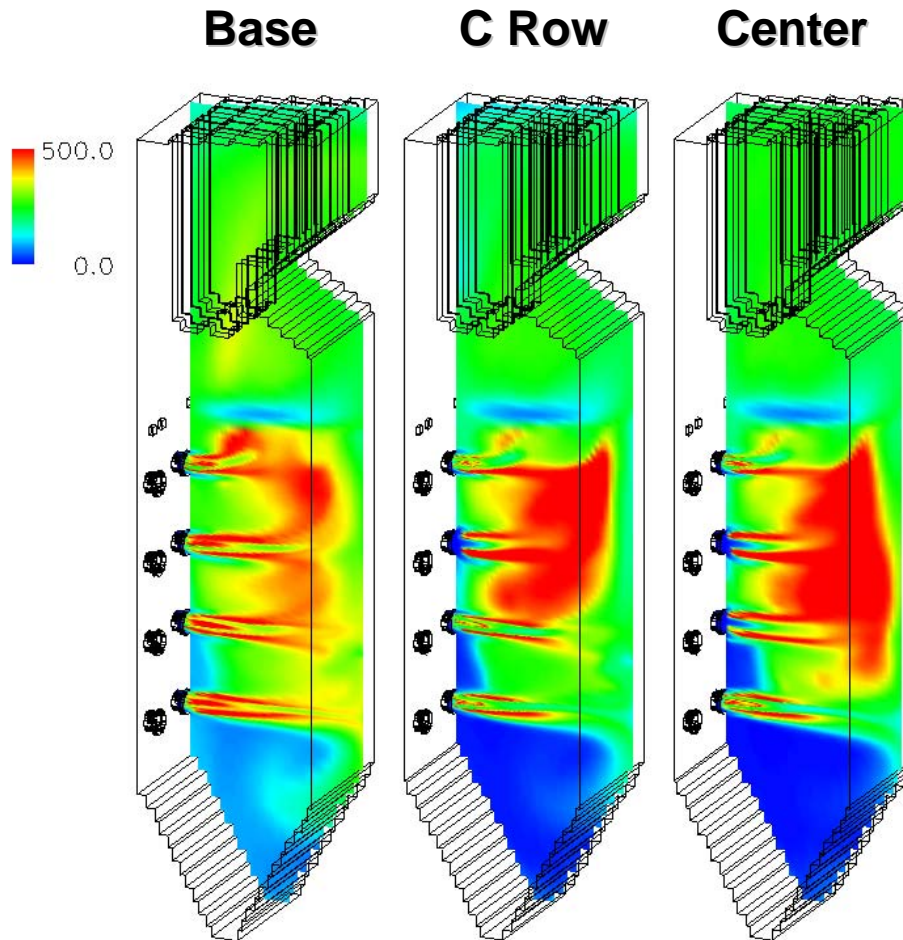
# Modeling Results

<u>Proximate Analysis</u>	<u>Coal</u>	<u>Biomass</u>
Volatiles	35.70%	48.47%
Fixed Carbon	51.69%	7.68%
Moisture	6.04%	43.47%
Ash	6.57%	0.39%
HHV (Btu/lb)	132701	4667

<u>Ultimate Analysis</u>		
C	72.80%	28.12%
H	5.69%	3.52%
O	6.10%	24.37%
N	1.50%	0.07%
S	1.30%	0.06%
Moisture	6.04%	43.47%
Ash	6.57%	0.39%

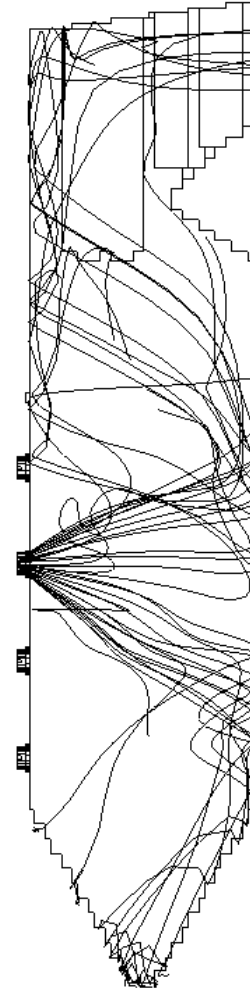
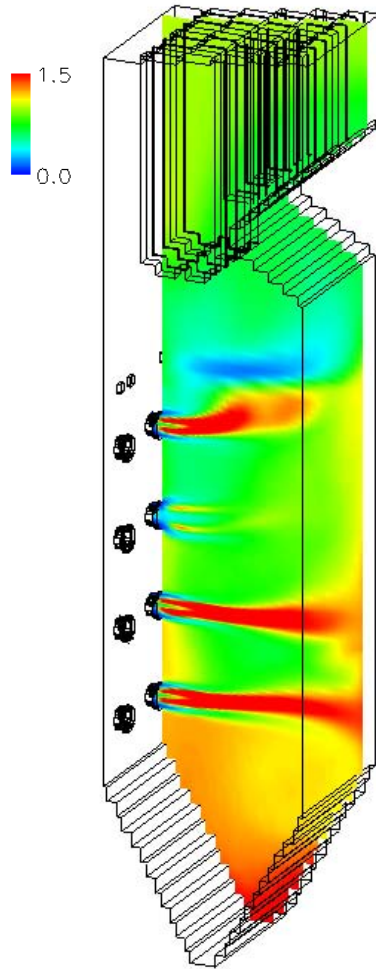
	Location	Temp. (°F)	O2 (%)	CO (ppm)	%Carbon-in-flyash	NOx (ppm)
Plant Estimates	Nose	2300	n/a	1500	n/a	n/a
	Economizer Exit	n/a	3.5	n/a	n/a	300
Baseline	Nose	2250	3.9	2930		297
	Furnace Exit	1920	3.7	340	16	292
"C" Row Biomass	Nose	2240	4.0	3370		269
	Furnace Exit	1940	3.8	140	10	264
Center 4 Biomass	Nose	2260	3.9	2020		264
	Furnace Exit	1940	3.7	110	12	267

# NOx Concentration



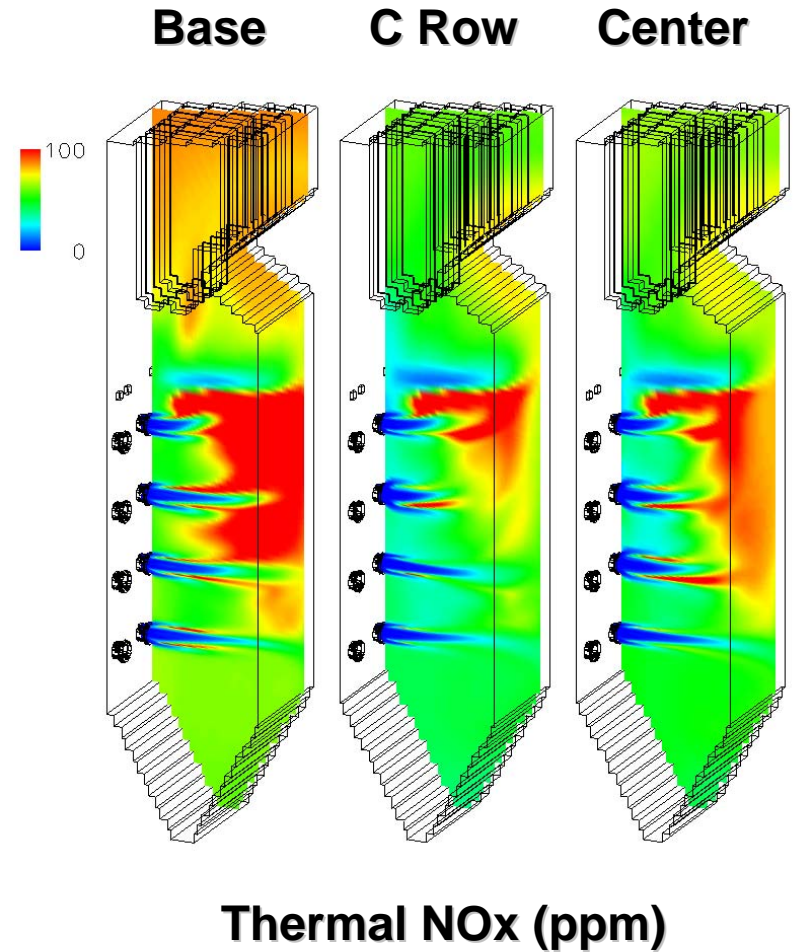
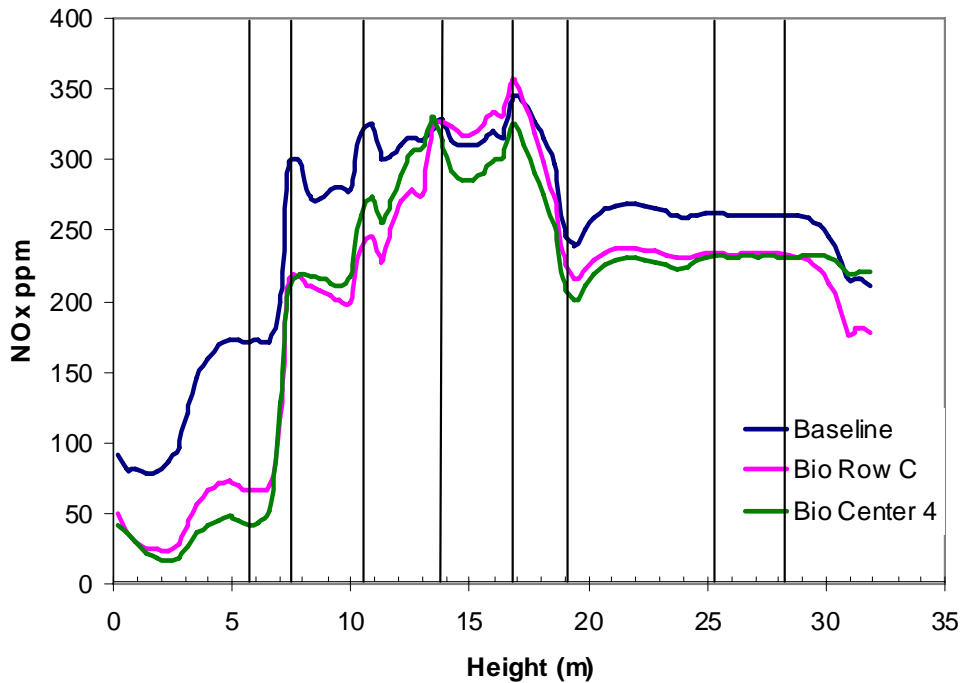
# Wood Particle Paths

**C Row  
Equivalence  
Ratio**



**Mean location  
of a 3.85 mm  
Particle  
trajectory**

# NOx Distribution



# Cyclone Co-firing

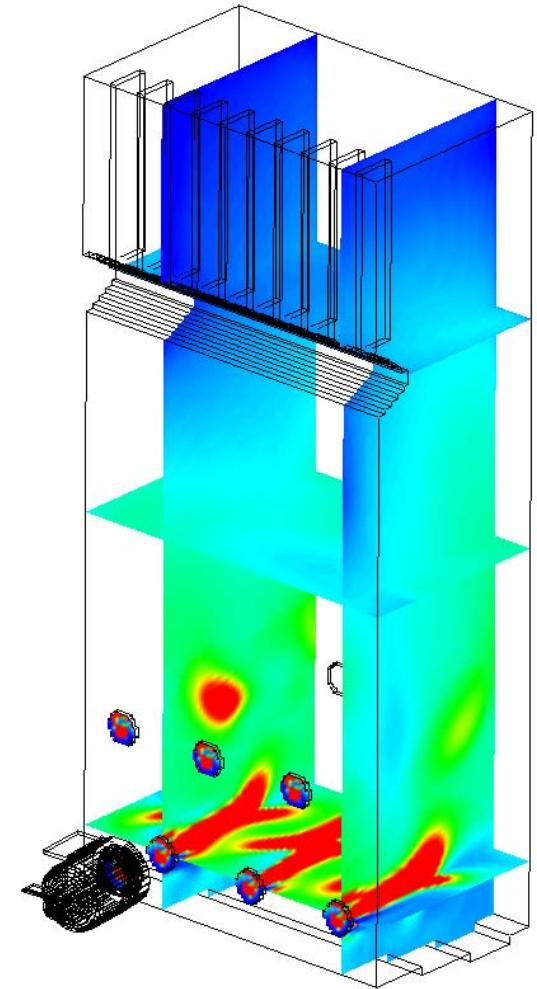
Blend Fuel Composition

	Coal	Wood	5% Co-Fire	10% Co-Fire	15% Co-Fire
C	70.70%	28.12%	64.91%	60.09%	56.00%
H	4.71%	3.52%	4.55%	4.41%	4.30%
O	5.39%	24.37%	7.97%	10.12%	11.94%
N	1.31%	0.07%	1.14%	1.00%	0.88%
S	2.65%	0.06%	2.29%	2.00%	1.75%
ash	7.74%	0.39%	6.74%	5.91%	5.20%
H2O	7.50%	43.47%	12.39%	16.47%	19.92%
HHV	13,945 Btu/lb	4,667 Btu/lb	12,684 Btu/lb	11,632 Btu/lb	10,742 Btu/lb

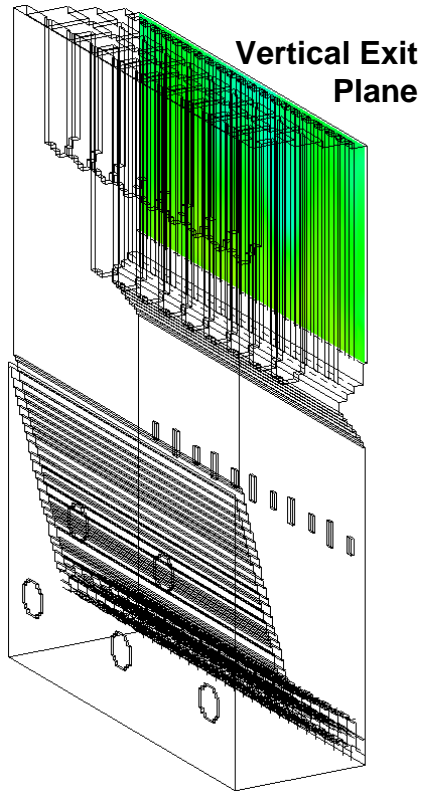
	Coal	Wood
Volatile Yield	36.6%	48.5%
Fixed Carbon	48.3%	7.7%
Density	84 lb/ft <sup>3</sup>	18 lb/ft <sup>3</sup>

Coal Ash Fusion Temperatures

$T_{250}$                       2350°F  
 $T_{80}$                          2500°F



# Furnace Exit Predictions



	Coal Only	5% Wood Co-Fire	10% Wood Co-Fire	15% Wood Co-Fire
Temperature	2332° F.	2355° F.	2354° F.	2363° F.
CO Concentration	3761 ppm	4876 ppm	4951 ppm	5373 ppm
O <sub>2</sub> Concentration	3.48%	3.41%	3.48%	3.40%
NO <sub>x</sub>	0.41 MBtu/hr	0.41 MBtu/hr	0.40 MBtu/hr	0.38 MBtu/hr
Carbon in Fly Ash	69%	62%	58%	56%
Fraction Ash Escaping	15%	17%	20%	20%
Total Wall Heat Transfer	694,741 Btu/hr	694,659 Btu/hr	669,966 Btu/hr	639,127 Btu/hr

- ➔ Predicted furnace exit NO<sub>x</sub> and carbon in fly ash decrease with wood co-firing
- ➔ The fraction of ash escaping the furnace, CO concentration, and temperature increase with wood co-firing
- ➔ Wall heat transfer decreases with increasing fraction of wood co-firing (the decreased sooting propensity of wood vs. coal results in less radiative heat transfer to the walls)